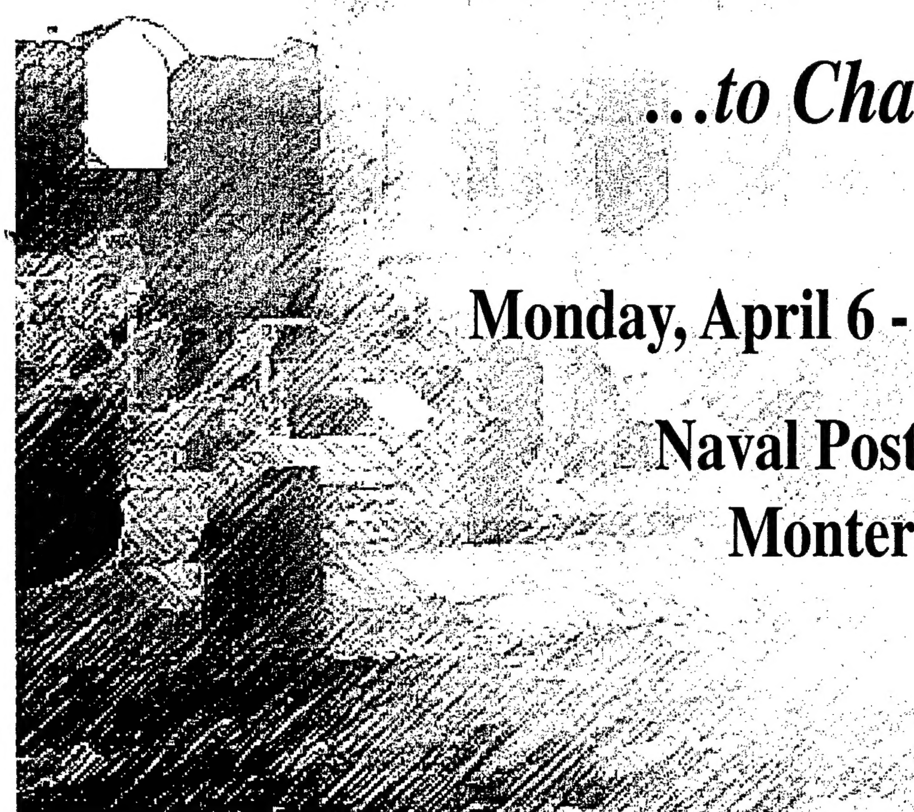
Proceedings of the Third International Symposium

Technology and the Mine Problem

...to Change the World

Monday, April 6 - Thursday, April 9, 1998

Naval Postgraduate School
Monterey, California



REPORT DOCUMENTATION PAGE

Form Approved
OBM No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1998

3. REPORT TYPE AND DATES COVERED
Proceedings

4. TITLE AND SUBTITLE
Synthetic Aperture Sonar Performance and Randomly Varying Sound Speeds in the Water Column

5. FUNDING NUMBERS
Job Order No.
Program Element No. 062435N
Project No.
Task No.
Accession No.

6. AUTHOR(S)
Timothy H. Ruppel

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Research Laboratory
Center for Environmental Acoustics
Stennis Space Center, MS 39529-5004

8. PERFORMING ORGANIZATION REPORT NUMBER
NRL/PP/7173--98-0109

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Proceedings of the Third International Symposium, Technology and the Mine Problem, 6-9 April 1998, Naval Postgraduate School, Monterey, CA

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Random sound speed fluctuations are prevalent in the ocean, even over distance scales of only a few meters (the so called "fine structure" and microstructure"). Since synthetic aperture sonar (SAS) measurements involve repeatedly "pinging" the target, these random sound speed fluctuations will cause the time of flight to the target to vary between pings. These time variations may produce significant phase errors in the array, degrading system performance. This paper intends to study the effect on SAS system performance of random sound speed fluctuations as evidenced in simulations.

The approach is to modify an existing **Matlab** simulation to include a ping-to-ping variation of the sound speed characterized by a Gaussian distribution, then compare results to the non-varying case.

14. SUBJECT TERMS
stochastic, SAS (synthetic aperture sonar), sound speed fluctuations, and Matlab simulation

15. NUMBER OF PAGES
3

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

Synthetic Aperture Sonar Performance and Randomly Varying Sound Speeds in the Water Column

Timothy H. Ruppel

Keywords— Stochastic, synthetic aperture sonar

I. Introduction

RANDOM sound speed fluctuations are prevalent in the ocean, even over distance scales of only a few meters (the so called "fine structure" and "microstructure").[1] Since synthetic aperture sonar (SAS) measurements involve repeatedly "pinging" the target, these random sound speed fluctuations will cause the time of flight to the target to vary between pings. These time variations may produce significant phase errors in the array, degrading system performance. This paper intends to study the effect on SAS system performance of random sound speed fluctuations as evidenced in simulations.

The approach is to modify an existing **Matlab** simulation to include a ping-to-ping variation of the sound speed characterized by a Gaussian distribution, then compare results to the non-varying case.

A. *Matlab Simulation*

The **Matlab** simulation used and modified for this paper is called `sassim.m` and was coded by José Fernandez at the Naval Coastal Systems Center in Panama City, FL. The program requires the frequency, the source and receiver array dimensions, the sound speed (assumed constant in time and space), the along-track velocity, the range to the target, the yaw angle and the steering angle. All inputs had default values which were used to describe a nominal environment during the simulations performed for this paper (see Section II).

The output of the simulation is a chart of the point response function of the SAS as a function of along-track position (normalized to the maximum response found).

The author modified the `sassim.m` program in order to investigate the effects of water column sound speed fluctuations on the simulated SAS response. The resulting program is called `sassim1.m`. One section of the original `sassim.m` modeled the source-to-target-to-receiver propagation in a loop over the number of pings required. This part of the code was modified so that for each ping, a sound speed was chosen from a Gaussian distribution whose mean and standard deviation were input by the user. The mean value of sound speed was used for all other processing. Hence, the code modeled random ping-to-ping sound speed variations.

Specifying a standard deviation of 0.0 to the modified `sassim1.m` generated identical results as the original `sassim.m`.

Timothy H. Ruppel is with the Ocean Acoustics Branch of the Naval Research Laboratory, Stennis Space Center, MS 39529. E-mail: tim.ruppel@nrlssc.navy.mil.

II. Simulation Results

The modified simulation was run with various frequencies and sound speed standard deviations. The remaining parameters are listed in Table I. The values of these parameters are the original program's defaults.

TABLE I
System Parameters Unchanged in the Simulations

Mean sound speed	1500 m/s
Receiver element spacing	0.0508 m
Number of Receiver elements	9
Number of Source elements	1
Along-track source offset	−0.0254 m
Along-track velocity	4 knots
Range to target	30 m
Array yaw angle	0°
Steering angle	0°

Figure 1 shows the change in the point response function as the sound speed is varied with a standard deviation σ of just 0.005 m/s (out of a mean of 1500 m/s). The central peak at $x = 0$ is broadened substantially so that localization becomes significantly more difficult. The acoustic frequency used in this simulation was 180 kHz, the default for `sassim.m`.

A. *Varying Sound Speed Distribution*

Figure 2 shows how SAS performance depends upon the sound speed distribution. The figure plots "mean error" as a function of sound speed standard deviation. The mean error is defined according to

$$E(\sigma) = \left\langle \left| \frac{s(\sigma) - s(0)}{s(0)} \right| \right\rangle \tag{1}$$

where $\langle\cdot\rangle$ indicates the arithmetic mean, $s(\sigma)$ is the SAS response (in dB relative to the maximum value) for the simulation where the sound speed standard deviation is σ. While the actual value is not terribly significant, equation 1 gives us a way of comparing the SAS response in the presence of sound speed variations to the SAS response in the absence of these variations.

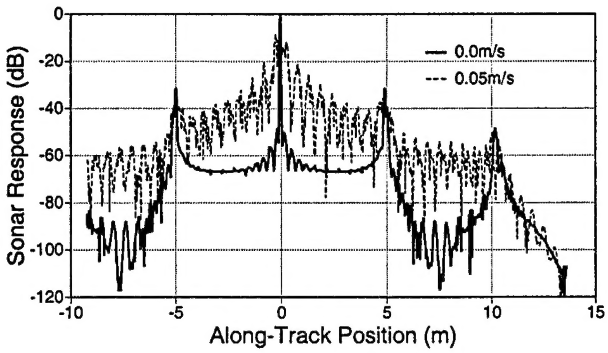


Fig. 1. Point response function for the SAS with the parameters in Table I, a frequency of 180 kHz and a sound speed standard deviation of 0 m/s and 0.05 m/s.

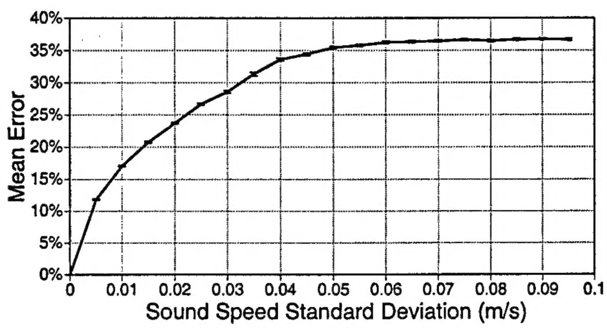


Fig. 2. Array performance as a function of standard deviation for a constant frequency of 180 kHz. "Mean error" is defined in equation 1.

In fact, the value plotted in figure 2 is the mean value of $E(\sigma)$ calculated over 100 trials for each data point, since the value of $E(\sigma)$ for any given run can be influenced by the exact values of the sound speed chosen from the distribution. The standard error is reflected in the plot with error bars.

Figure 2 shows that the SAS performance degrades with increasing sound speed standard deviation, as one might expect. It is perhaps alarming that sound speed variations of only 5–10 cm/s are enough to seriously affect performance. These sorts of fluctuations are well within the range of variations observed in the ocean (see Section II-C below).

B. Varying Frequency

Figure 3 shows how SAS performance with a randomly varying sound speed depends upon the acoustic frequency. The figure plots mean error as defined in equation 1 against frequency, again using the mean value of $E(\sigma)$ over 100 trials.

Figure 3 shows that the SAS performance degrades with increasing frequency. One way of improving the performance of an SAS in a stochastic environment would therefore be to use the lowest frequency practical.

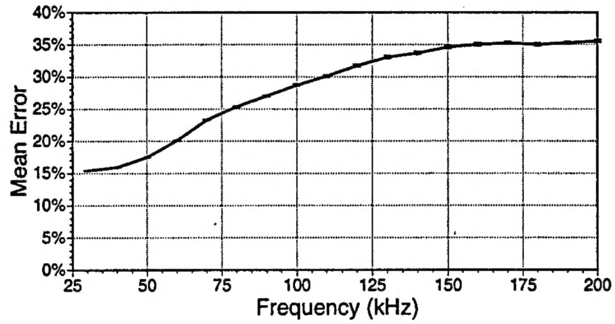


Fig. 3. Array performance as a function of frequency for a constant standard deviation of 0.05 m/s. "Mean error" is defined in equation 1.

TABLE II

MEAN ERRORS CALCULATED FROM SIMULATIONS USING A SOUND SPEED VARIANCE DERIVED FROM TEMPERATURE FLUCTUATIONS MEASURED IN EXPERIMENTS CONDUCTED OFF PANAMA CITY, FL IN APRIL, 1995. THE RANGE TO THE TARGET HERE IS 90 M.

Date	$\langle \Delta T \rangle$ °C	$\langle \Delta c \rangle$ (m/s)	Mean Error (%) 50 kHz	180 kHz
4/17 AM	0.017	0.043	16.15±0.04	34.11±0.25
4/17 PM	0.018	0.046	16.69±0.05	34.82±0.22
4/18 AM	0.021	0.054	18.10±0.05	35.98±0.20
4/18 AM	0.057	0.145	29.27±0.19	36.33±0.16
4/18 PM	0.143	0.365	35.64±0.15	36.41±0.16
4/18 PM	0.143	0.365	35.64±0.15	36.41±0.16

C. Expectation of Performance Under Actual Conditions

In high frequency medium coherence experiments conducted off Panama City, FL in April, 1995, Stanic collected data on temporal variability of the ocean temperature $\langle \Delta T \rangle$ using thermistors with a response of 23 ms.[2] With an ambient ocean temperature of about 22.5°C, the corresponding variation in sound speed $\langle \Delta c \rangle$ can be calculated.[3] Table II gives the expected values of $E(\sigma)$ (with associated standard errors) for these values of sound speed variances. In this table, the range to the target is 90 m, not 30 m as in figures 1–3.

III. Conclusions

An independently produced simulation of SAS performance was modified to allow a ping-to-ping variation of the sound speed. The resulting SAS response was compared with no-variation responses to determine the impact that time-varying sound speeds would have on SAS performance.

It was found that small variations in sound speed, comparable to those found in experimental tests performed off Panama City, FL, can significantly degrade SAS performance, especially at high frequencies.

IV. Acknowledgments

This work was funded by the Office of Naval Research.

REFERENCES

[1] Hassan B. Ali, "Ocean variability in shallow-water acoustics and the dual role of the sea bottom," *IEEE Journal of Oceanic Engineering*, vol. 18, pp. 31–41, 1993.

[2] Steve Stanic, "private communications," .

[3] L. Brekhovskikh and Yu. Lysanov, *Fundamentals of Ocean Acoustics*, Springer-Verlag, New York, 1982.